Heat treatment of tool steels

Case studies

BÖHLER

BÖHLER EDELSTAHL GMBH & Co KG
MARIAZELLER STRASSE 25
POSTFACH 96
A-8605 KAPFENBERG/AUSTRIA
TELEFON: (+43) 3862/20-7181
TELEFAX: (+43) 3862/20-7576
E-mail: info@bohler-edelstahl.com
www.bohler-edelstahl.com

1. High Speed Steel (HS 6-5-2)

Verwendung

Gewinde- und Spiralbohrer, Reibahlen, Räumwerkzeuge, Metallsägen, Fräser aller Art, Holzbearbeitungswerkzeuge, Kaltarbeitswerkzeuge.

Applications

Taps, twist drills, reamers, broaching tools, metal saws, milling tools of all types, woodworking tools, cold work tools.

Chemische Zusammensetzung (Anhaltswerte in %) / Chemical composition (average %)				
C	**Cr**	**Mo**	**V**	**W**
0,90	4,10	5,00	1,80	6,20

Normen **Standards**

DIN / EN	AISI	UNS	BS
~ 1.3554 LW	~ M2 reg. C	~ T11302	~ BM2
< 1.3343 >			
HS6-5-2C			

General overview

Properties

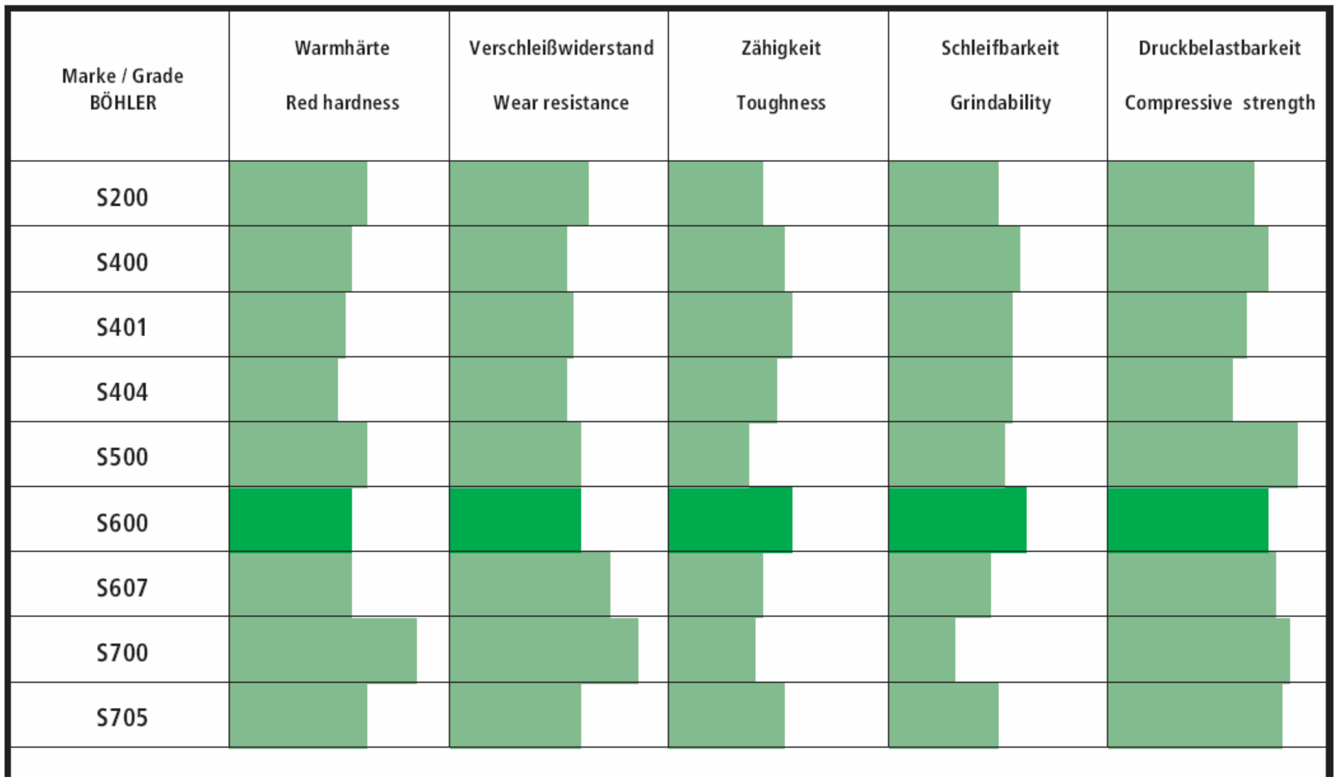
Tungsten-molybdenum high speed steel with excellent toughness and cutting properties, for a wide variety of uses.
BÖHLER S600 is also available in the special grade ISORAPID for heavy duty tools.

BÖHLER S601 a modified version of BÖHLER S600 and corresponding to customer's specifications for AISI M2.

Comparison of properties

Qualitativer Vergleich der wichtigsten Eigenschaftsmerkmale

Qualitative comparison of the major steel properties



Annealing:

770 to 840°C (1418 to 1544°F) / Controlled slow cooling in furnace (10 to 20°C/h / (50 to 68°F/h) to approx. 600°C (1110°F),
air cooling. Hardness after annealing:
max. 280 Brinell.

Stress relieving:

600 to 650°C (1112 to 1202°F)
Slow cooling in furnace.
To relieve stresses set up by extensive machining or in tools of intricate shape.
After through heating, hold in neutral atmosphere for 1 to 2 hours.

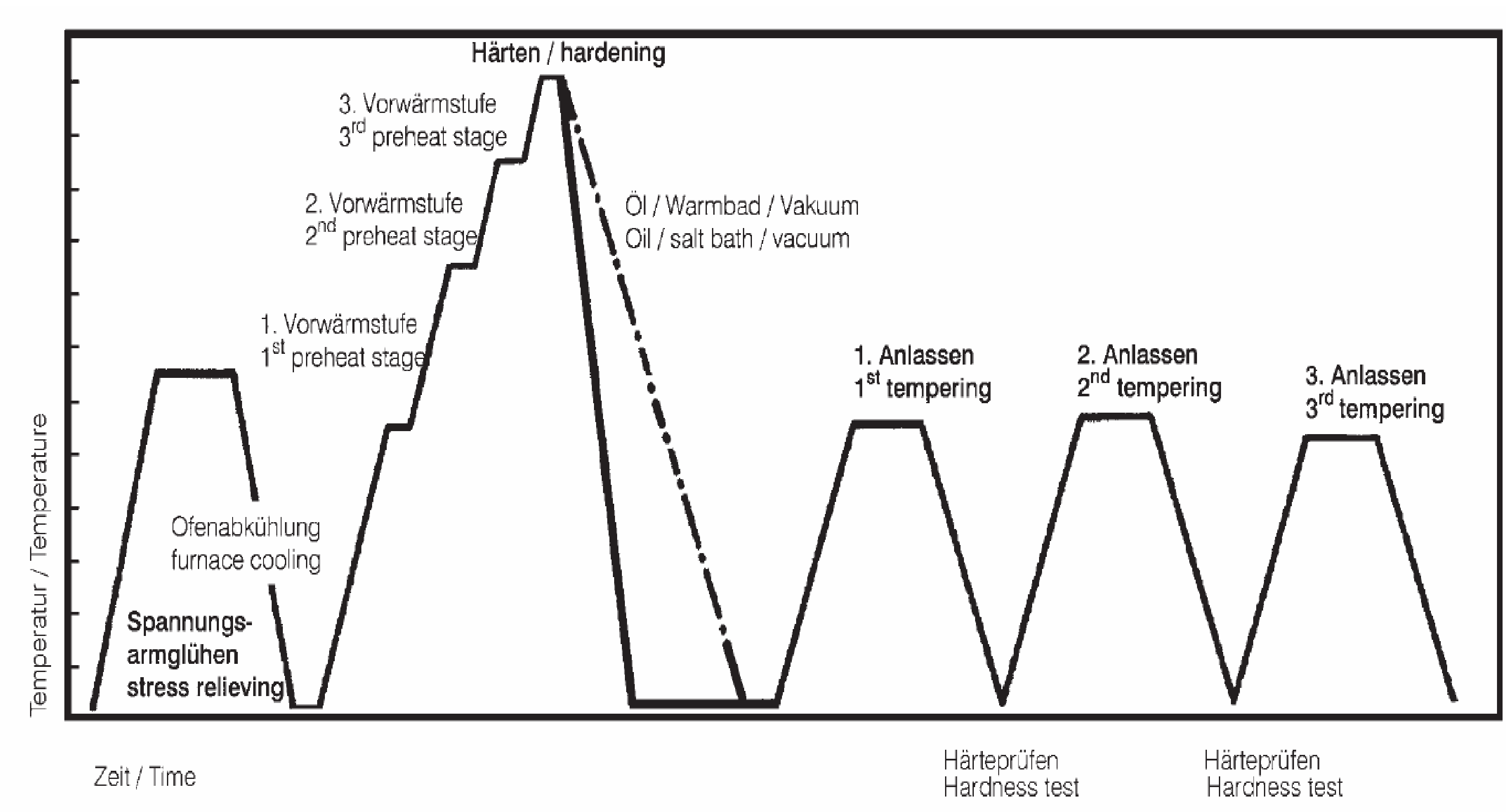
Hardening:

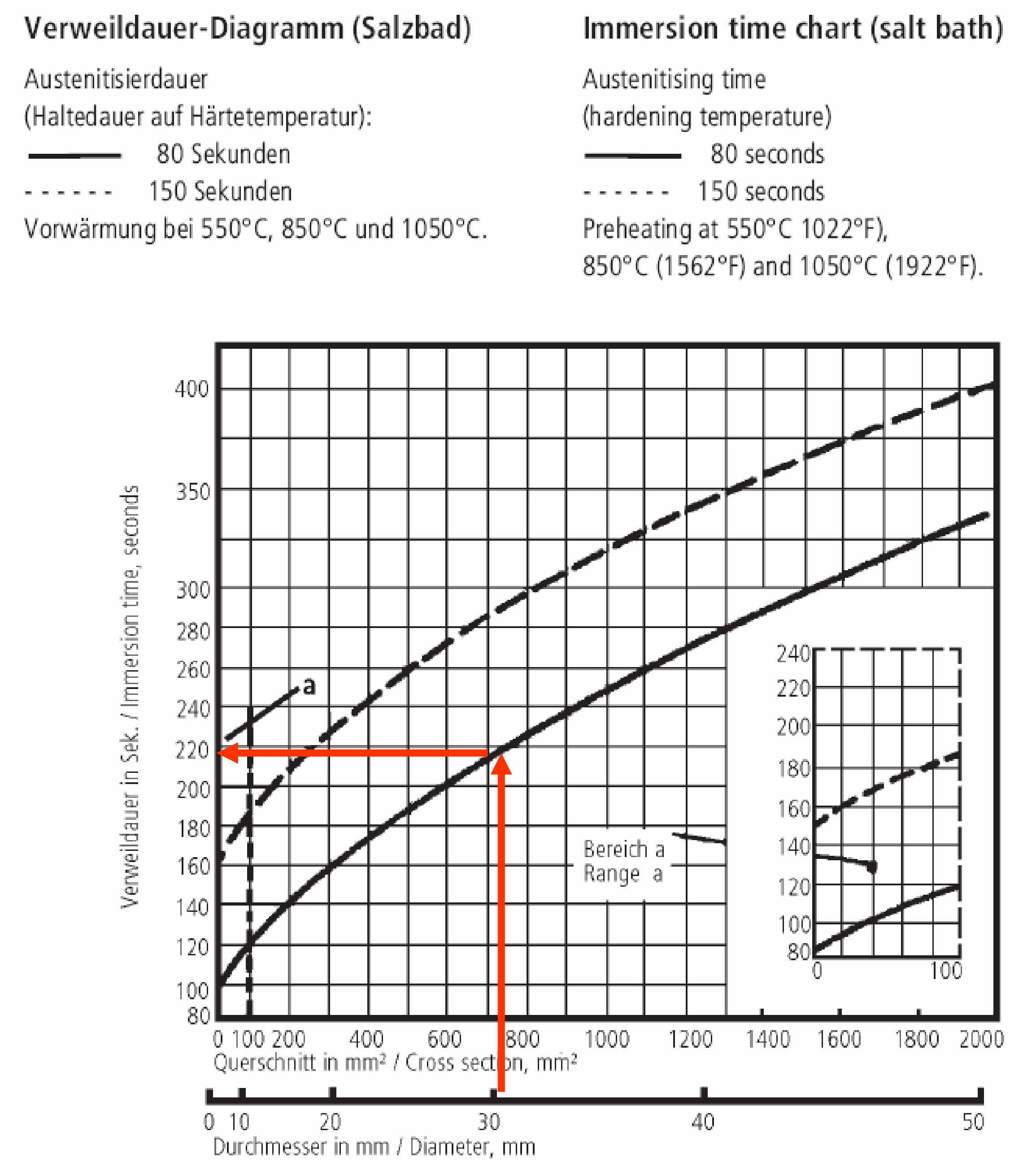
1190 to 1230°C (2174 to 2246°F)
Oil, air, salt bath (500 - 550°C (932 - 1022°F), gas.
Upper temperature range for parts of simple shape, lower for parts of complex shape.
For coldworking tools also lower temperatures are of inportance for higher toughness.
Soaking time after heating up the whole section of a workpiece 80 seconds minimum is required for dissolving sufficient carbides.
Maximum soaking time 150 seconds to avoid detriments by oversoaking.

Tempering:

Slow heating to tempering temperature immediately after hardening/time in furnace:
1 hour for every 20 mm of workpiece thickness, but not less than 2 hours/ air cooling (minimum holding time: 1 hour).
1st tempering and 2nd tempering to desired working hardness.
Average obtainable hardness values are shown in the tempering chart.
3rd tempering for stress relieving,
30 - 50°C (86-122°F) below highest tempering temperature.
Obtainable hardness after tempering:
64 - 66 HRC.

Heat treatment sequence





Immersion time as function of size and austenising time

Anlassschaubild

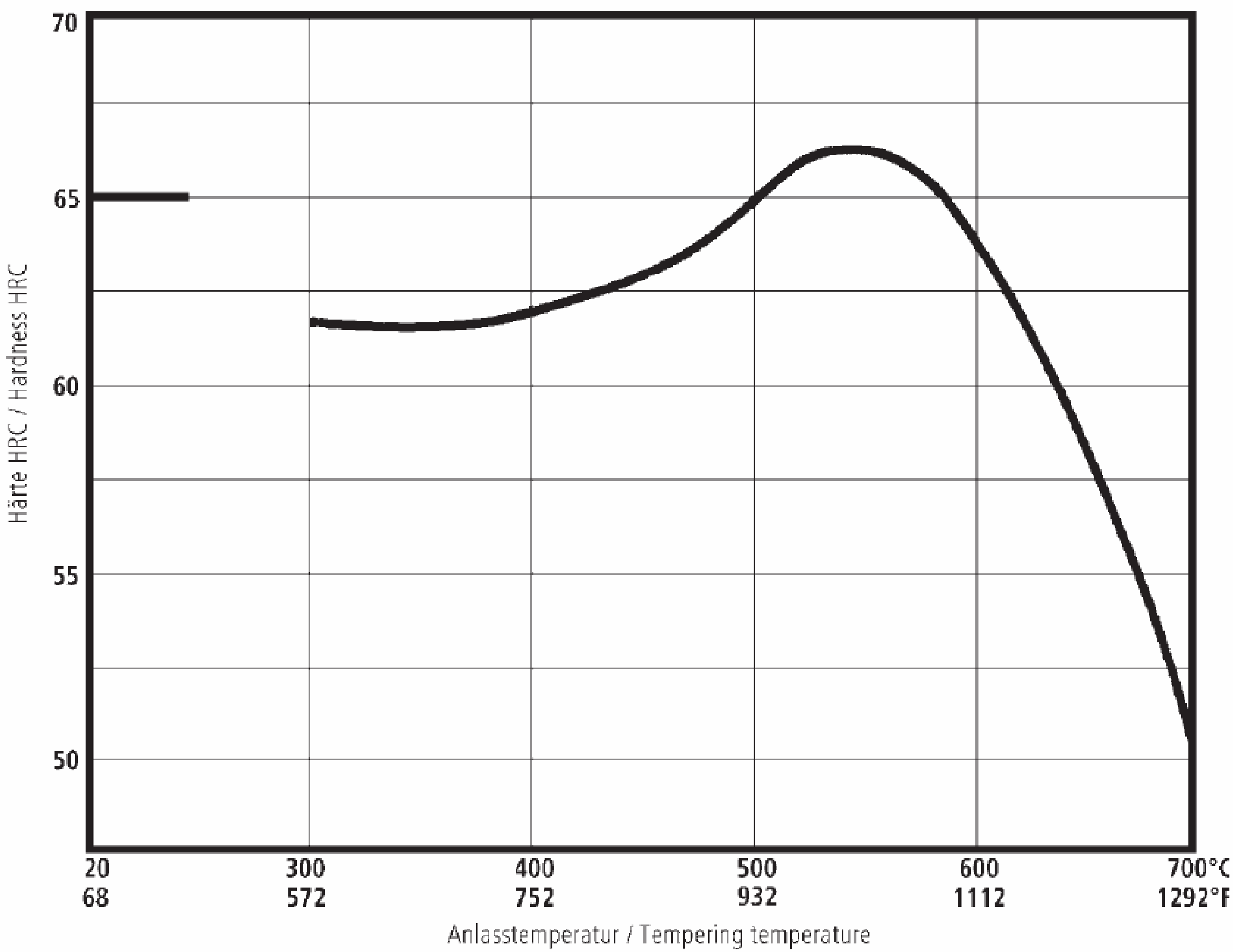
Härtetemperatur: 1210°C

Probenquerschnitt: Vkt. 20 mm

Tempering chart

Hardening temperature: 1210°C (2210°F)

Specimen size: square 20 mm



Tempering for optimum hardness. Precipitation of carbides.

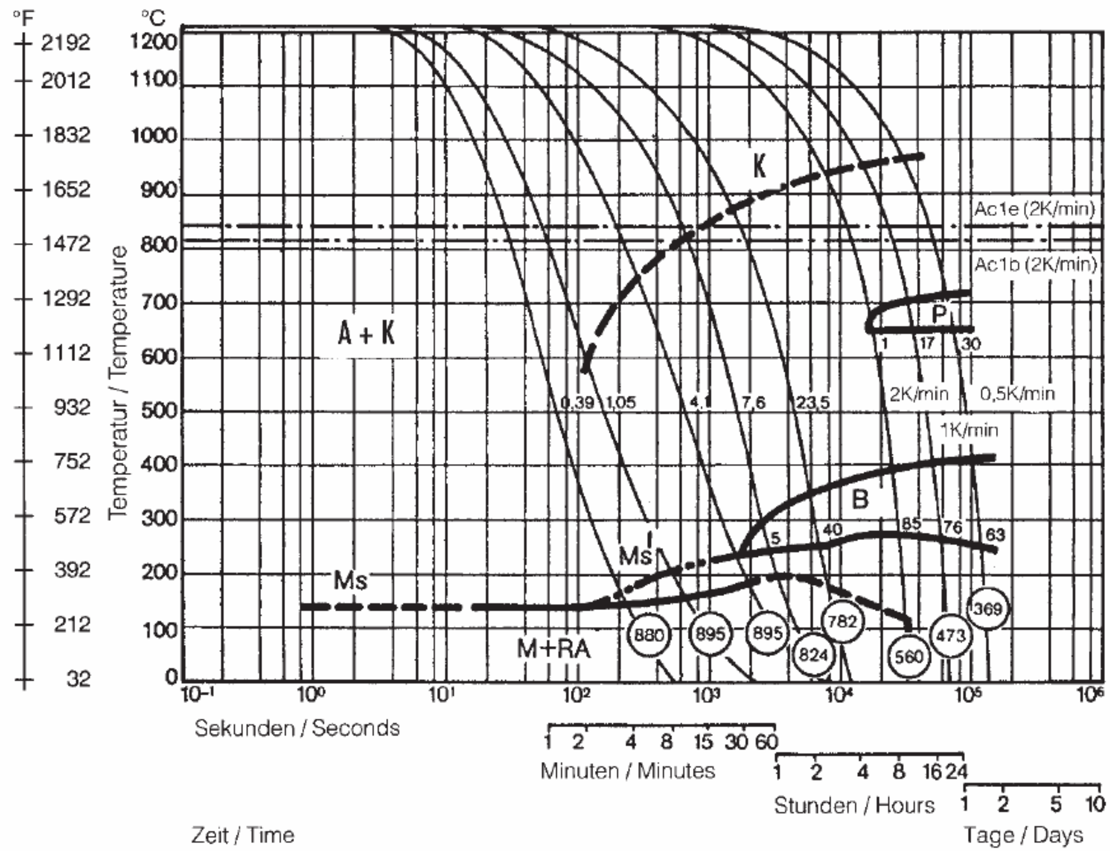
CCT diagram of HS 6-5-2

Austenitisierungstemperatur: 1210°C
Haltedauer: 150 Sekunden

◯ Härte in HV
1 . . . 30 Gefügeanteile in %
0,39 . . . 23,5 Abkühlungsparameter, d. h. Abkühlungsdauer von 800°C bis 500°C in s x 10^{-2}
2 K/min .... 0,5 K/min Abkühlungsgeschwindigkeit in K/min im Bereich von 800 - 500°C
Ms-Ms'....Bereich der Korngrenzenmartensitbildung

Austenitising temperature: 1210°C (2210°F)
Holding time: 150 seconds

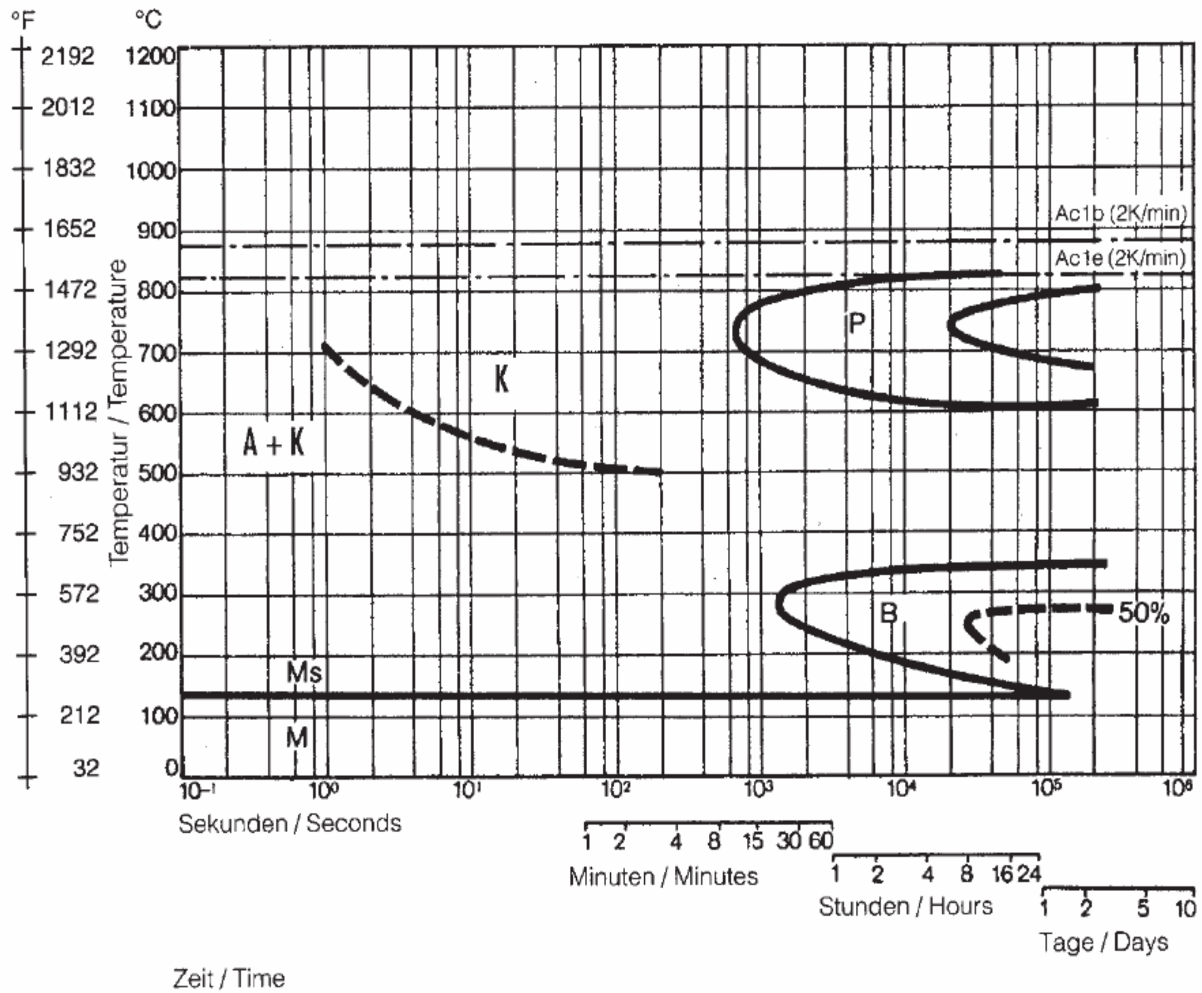
◯ Vickers hardness
1 . . . 30 phase percentages
0.39 . . . 23.5 cooling parameter, i.e. duration of cooling from 800-500°C (1472-932°F) in s x 10^{-2}
2 K/min .... 0.5 K/min cooling rate in K/min in the 800 - 500°C (1472 - 932°F) range
Ms-Ms'....range of grain boundary martensite formation



Isothermal TTT diagram of HS 6-5-2

Austenitisierungstemperatur: 1210°C
Haltedauer: 150 Sekunden

Austenitising temperature: 1210°C (2210°F)
Holding time: 150 seconds



2. Cold working tool steel (K11)

Chemische Zusammensetzung (Anhaltswerte in %) / Chemical composition (average %)						
C	Si	Mn	Cr	Mo	V	W
1,60	0,35	0,30	11,50	0,60	0,30	0,50

Normen **Standards**

DIN / EN	BS	AISI	UNS
< 1.2601 > X165CrMoV12	~ BD2	~ D2	~ T30402

GOST	UNI
~ Ch12M	X165CrMoW12 KU

Properties

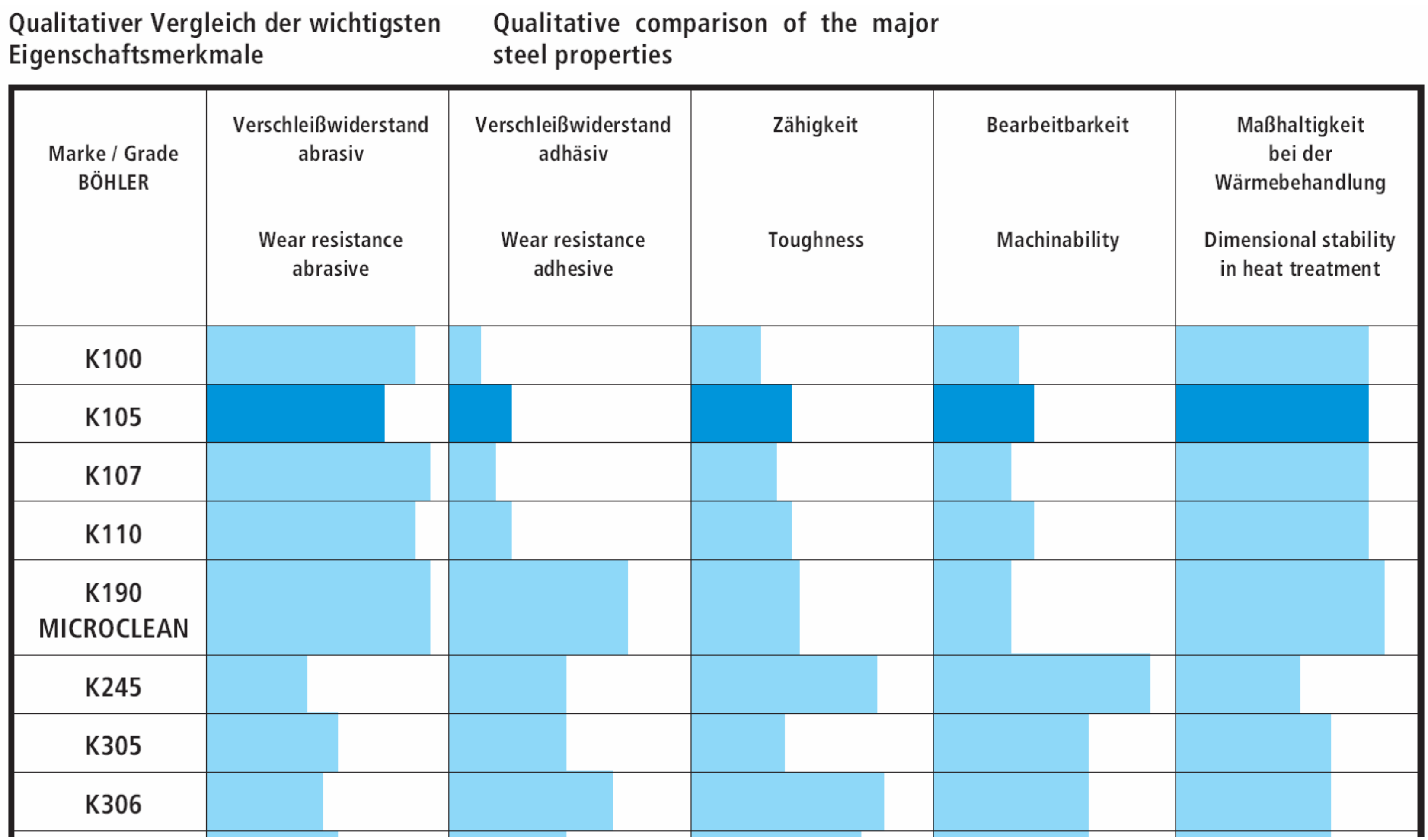
Dimensionally stable, high carbon, high-chromium (12%) steel.
Particularly suitable for air hardening.
Good toughness.

General overview

Application

High-duty cutting tools (dies and punches), blanking and punching tools, woodworking tools, shear blades for cutting light-gauge material, thread rolling tools, tools for drawing, deep drawing and cold extrusion, pressing tools for the ceramics and pharmaceutical industries, cold rools (working rolls) for multiple-roll stands, measuring instruments and gauges, small moulds for the plastics industry where excellent wear resistance is required.

Comparison of properties



Heat treatment (1)

Annealing:

800 to 850°C

Slow controlled cooling in furnace at a rate of 10 to 20°C/hr down to approx. 600°C, further cooling in air. Hardness after annealing:

max. 250 HB.

Stress relieving:

650 - 700°C

Slow cooling in furnace; intended to relieve stresses set up by extensive machining, or in complex shapes.

After through heating, hold in neutral atmosphere for 1 to 2 hours.

Hardening:

980 - 1010°C

oil, salt bath from (220 to 250°C or 500 to 550°C), air, gas.

Tools of intricate shape or with sharp edges should preferably be hardened in air or salt bath.

Holding time after temperature equalization:

15 to 30 minutes.

Obtainable hardness: 63 - 65 HRC.

Tempering:

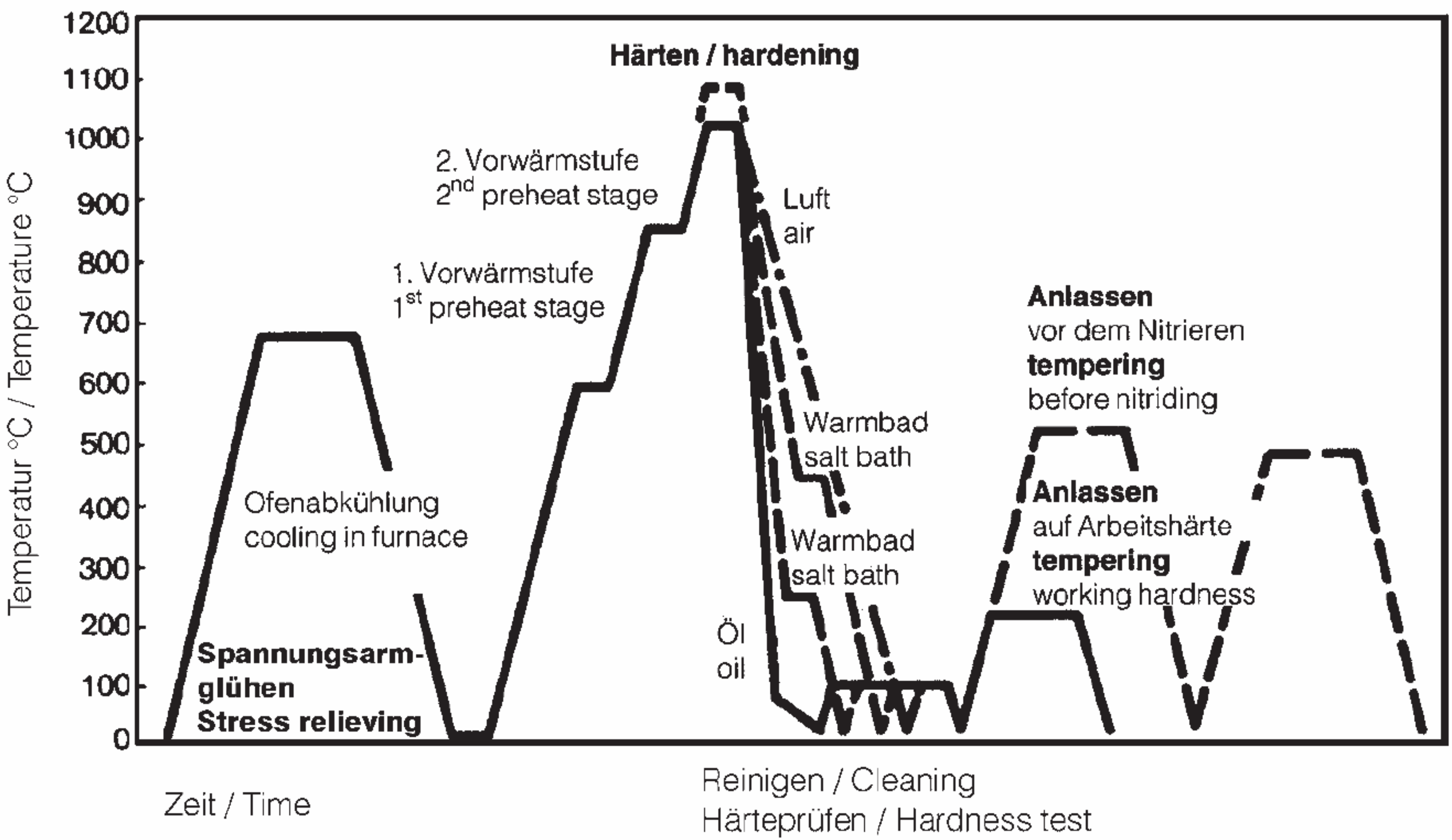
Slow heating to tempering temperature immediately after hardening/time in furnace 1 hour for each 20 mm of workpiece thickness but at least 2 hours/cooling in air.

For average hardness figures to be obtained please refer to the tempering chart.

For certain cases we r ecommend to reduce tempering temperature and increase holding time.

For certain applications requiring improved retention of hardness, a nitriding treatment is recommended (see below).

Heat treatment sequence



Anlassschaubild:

Härtetemperatur:

—— 980°C

- - - - - 1080°C

Probenquerschnitt: Vkt. 20 mm

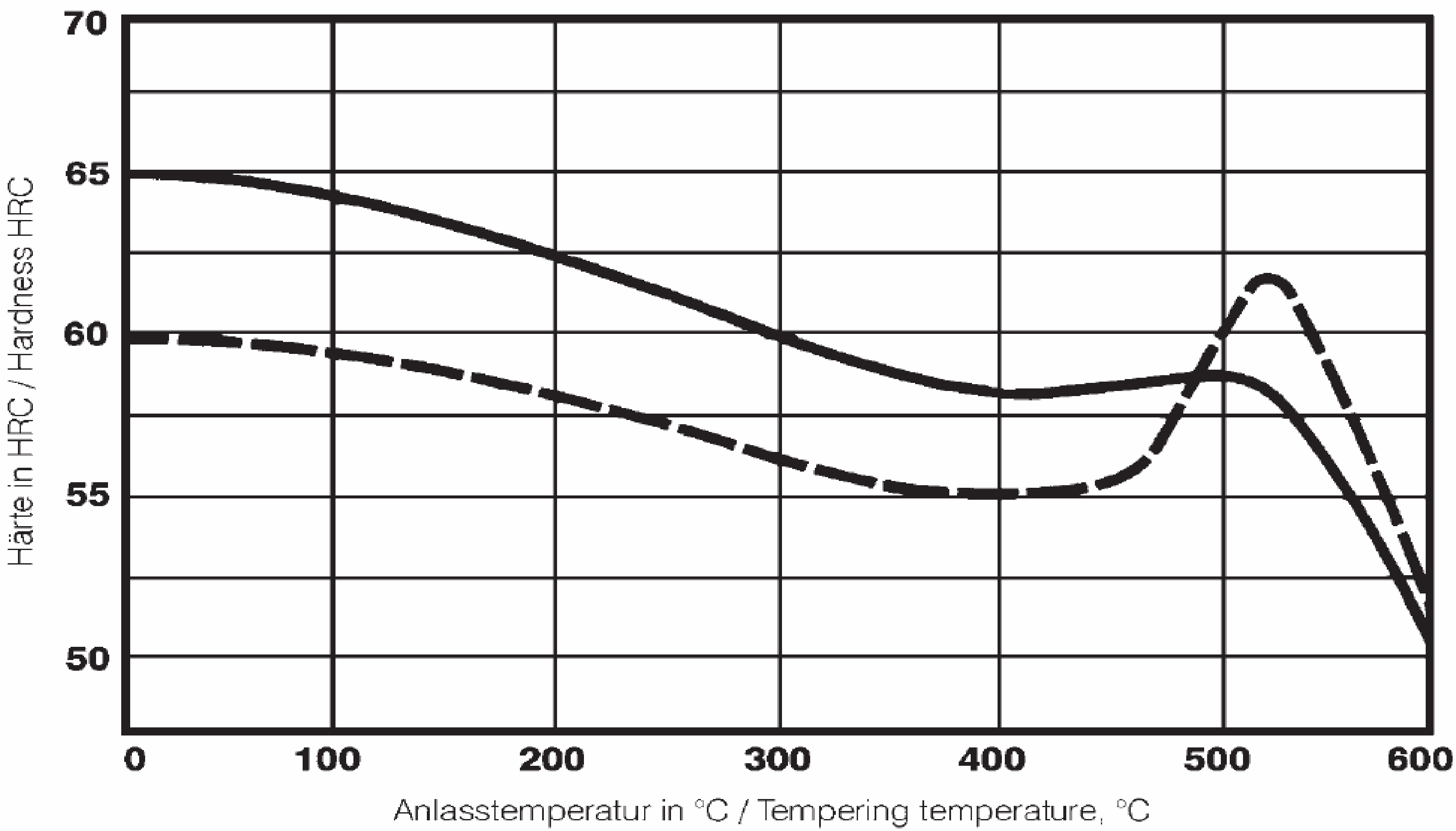
Tempering chart:

Hardening temperature:

—— 980°C

- - - - - 1080°C

Specimen size: square 20 mm



CCT diagram of K11

ZTU-Schaubild
für kontinuierliche Abkühlung /
Continuous cooling
CCT curves

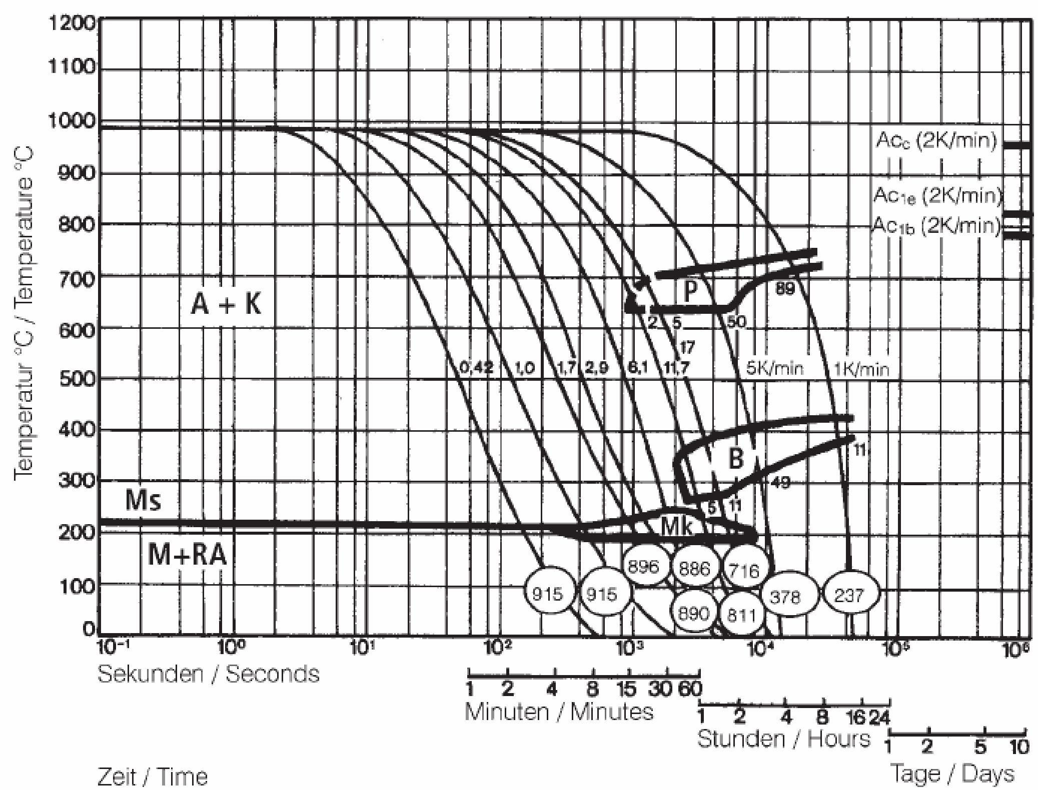
Chemische Zusammensetzung (Anhaltswerte in %) / Chemical composition (average %)									
C	Si	Mn	P	S	Cr	Mo	Ni	V	W
1,65	0,27	0,39	0,025	0,019	11,17	0,50	0,20	0,16	0,59

Austenitisierungstemperatur: 980°C
Haltedauer: 30 Minuten

◯ Härte in HV
2 . . . 50 Gefügeanteile in %
0,42 . . . 17 Abkühlungsparameter (λ), d. h.
Abkühlungsdauer von 800°C bis 500°C in s x 10^{-2}
5 .... 1K/min Abkühlungsgeschwindigkeit in K/min
im Bereich von 800°C bis 500°C
Mk ..... Korngrenzenmartensit

Austenitising temperature: 980°C
Holding time: 30 minutes

◯ Vickers hardness
2 . . . 50 phase percentages
0.42 . . . 17 cooling parameter (λ), i.e. duration
of cooling from 800°C to 500°C in s x 10^{-2}
5 .... 1K/min cooling rate in K/min in the
800°C to 500°C range
Mk..... Grain boundary martensite



Isothermal TTT diagram of K11

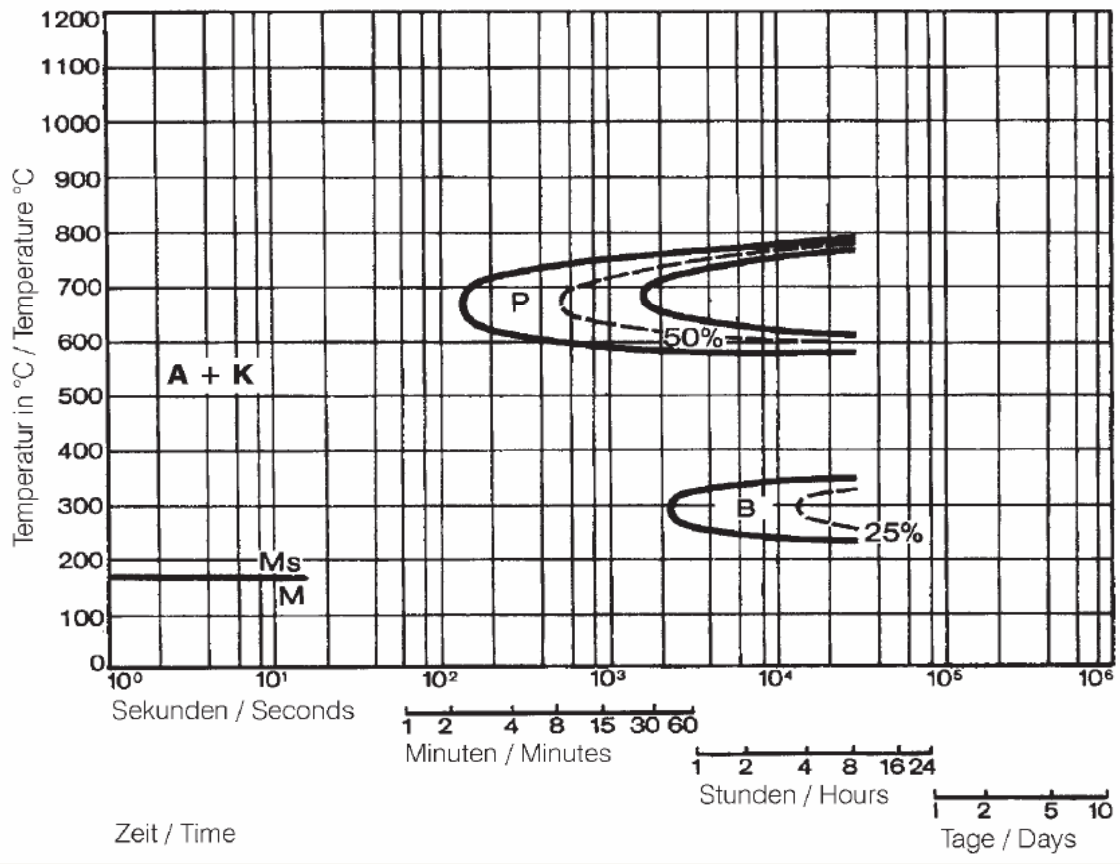
Isothermisches ZTU-Schaubild / Isothermal TTT curves

Chemische Zusammensetzung (Anhaltswerte in %) / Chemical composition (average %)									
C	Si	Mn	P	S	Cr	Mo	Ni	V	W
1,65	0,27	0,39	0,025	0,019	11,17	0,50	0,20	0,16	0,59

Austenitisierungstemperatur: 980°C
Haltedauer: 30 Minuten

Austenitising temperature: 980°C
Holding time: 30 minutes

A ..... Austenit / Austenite
B ..... Bainit / Bainite
P ..... Perlit / Perlite
K ..... Karbid / Carbide
M .... Martensit / Martensite

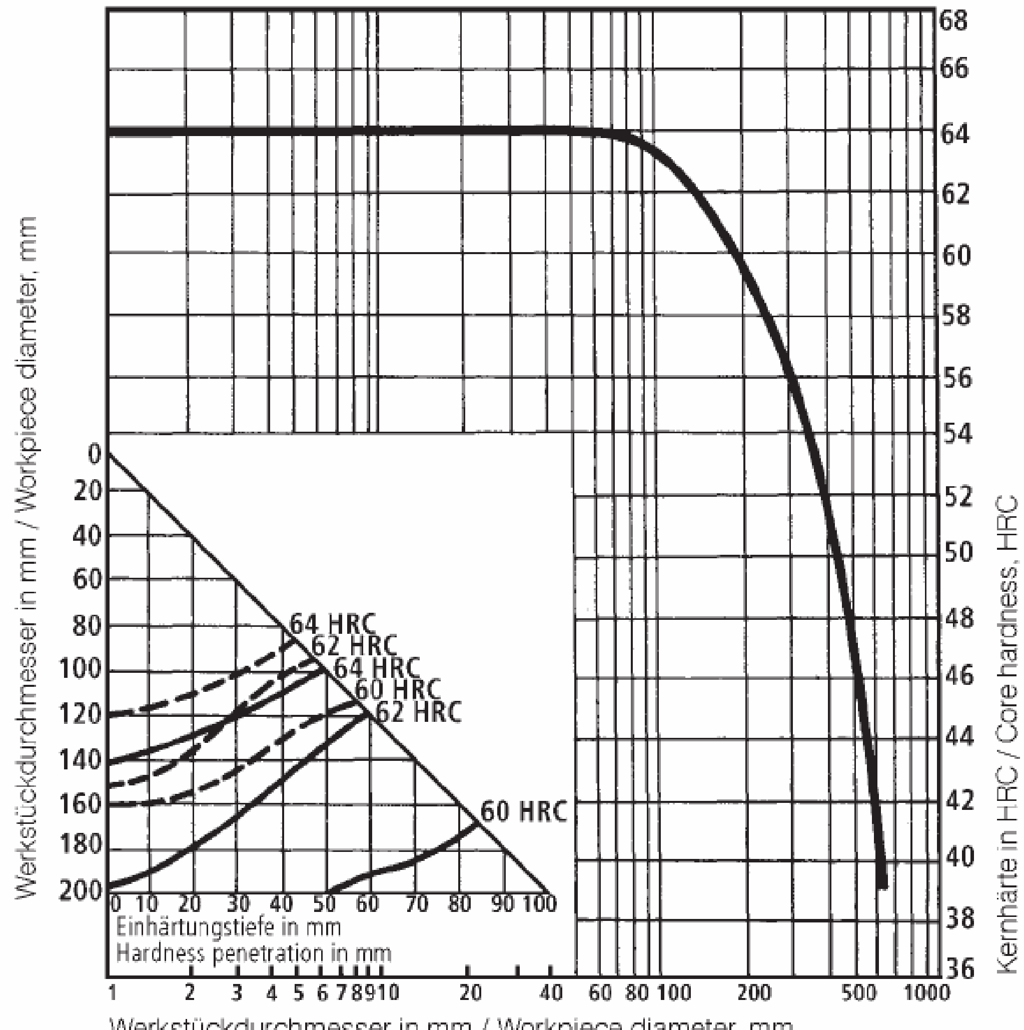


Abhängigkeit der Kernhärte und der Einhärtetiefe vom Werkstückdurchmesser

Influence of work diameter on core hardness and hardness penetration

Härtetemperatur: 980°C
Härtemittel:
Öl (solid line)
Luft (dashed line)

Quenched from: 980°C
Quenchant:
Oil (solid line)
Air (dashed line)



3. Powder metallurgical (PM) cold working steel (K390 MICROCLEAN)

3 Faktoren machen den BÖHLER K390 MICROCLEAN so wirtschaftlich:

- Extrem hoher Verschleißwiderstand
- Hervorragende Zähigkeit
- Höchste Druckbelastbarkeit

3 factors contribute to the cost efficiency of BÖHLER K390 MICROCLEAN:

- an extremely high wear resistance
- outstanding toughness
- high compressive strength

Chemische Zusammensetzung (Anhaltswerte in %) / Chemical composition (average %)						
C	Si	Cr	Mo	V	W	Co
2.45	0.55	4.15	3.75	9.00	1.00	2.00

BÖHLER K390 MICROCLEAN owes its superior properties above all to the powder-metallurgical production process. The main advantages of BÖHLER MICROCLEAN steels over conventional steels are:

- uniform carbide distribution and small carbide size
- isotropic behaviour due to improved homogeneity and the absence of segregations

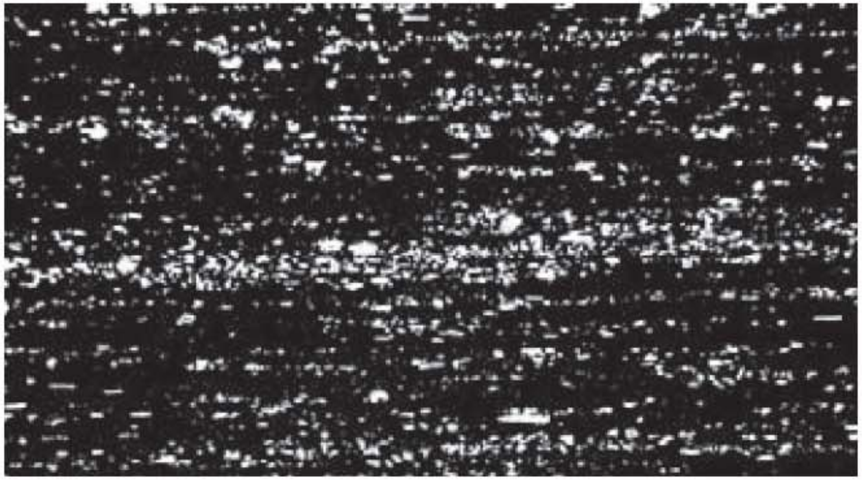
Comparison of conventional and PM steel structure

Vergleich der Karbidverteilung und Karbidgröße

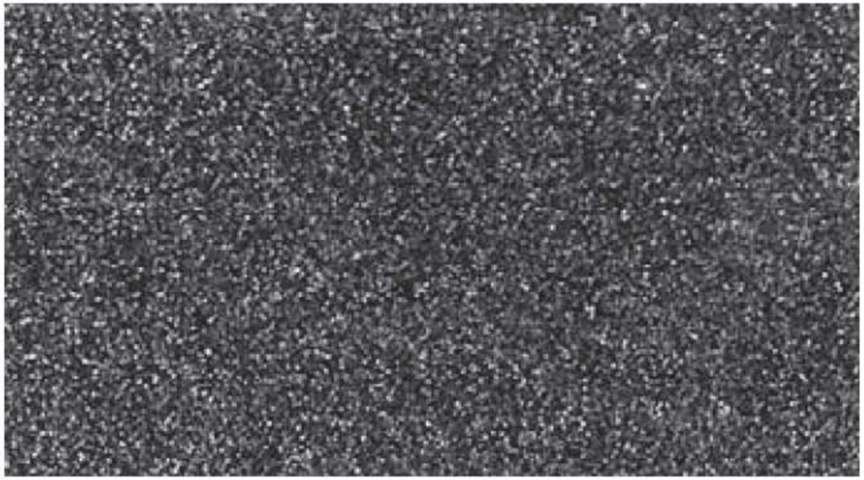
Vergleich **BÖHLER K390 MICROCLEAN** mit konventionell hergestelltem ledeburitischem 12%-igem Chromstahl (V = 100:1)

Comparison of carbide size and distribution

Comparison of **BÖHLER K390 MICROCLEAN** with a high carbon, 12% chromium steel produced by conventional methods (M = 100x)

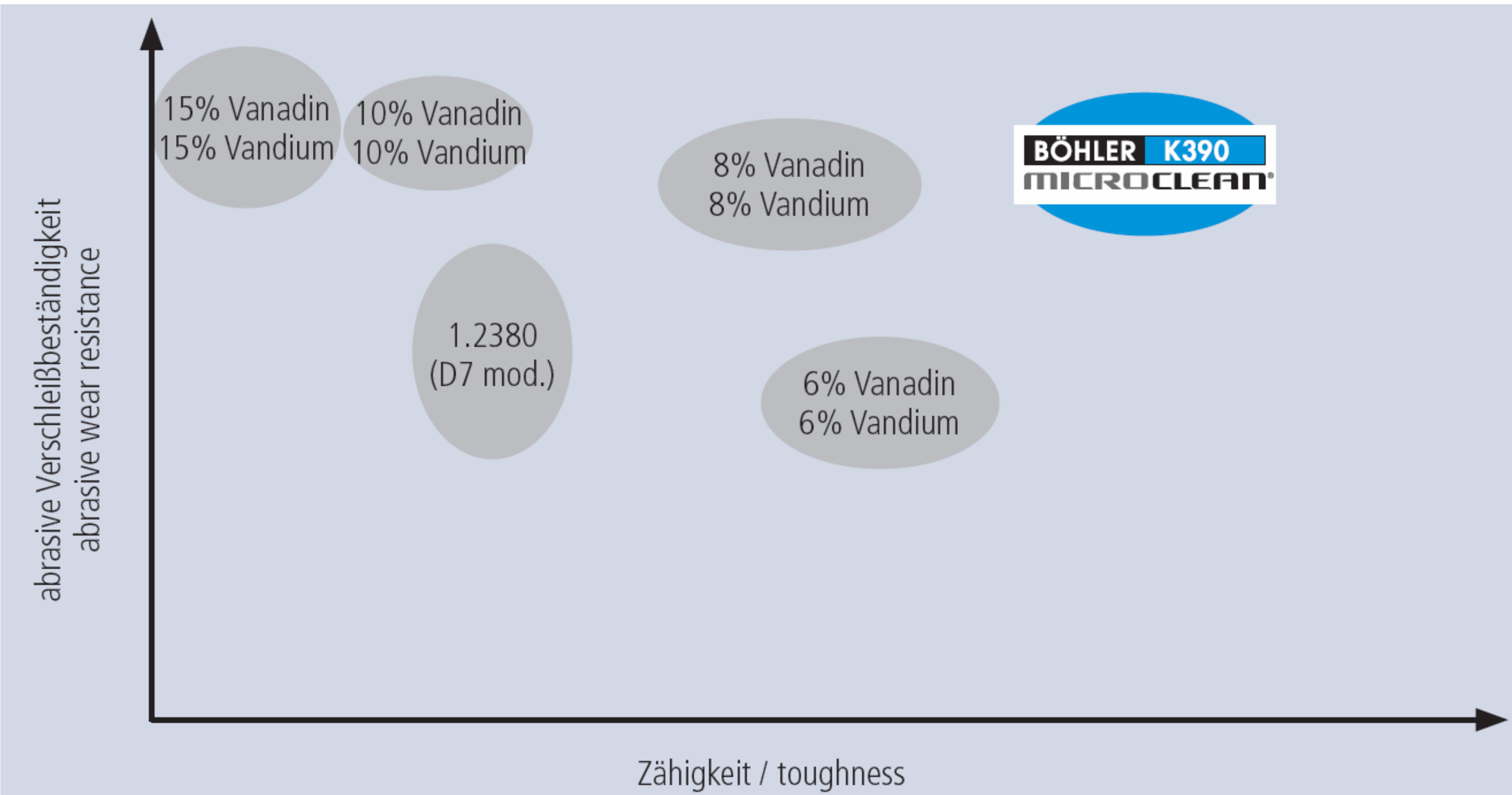


12%-iger Chromstahl / 12% chromium steel (AISI D2)



BÖHLER K390 MICROCLEAN

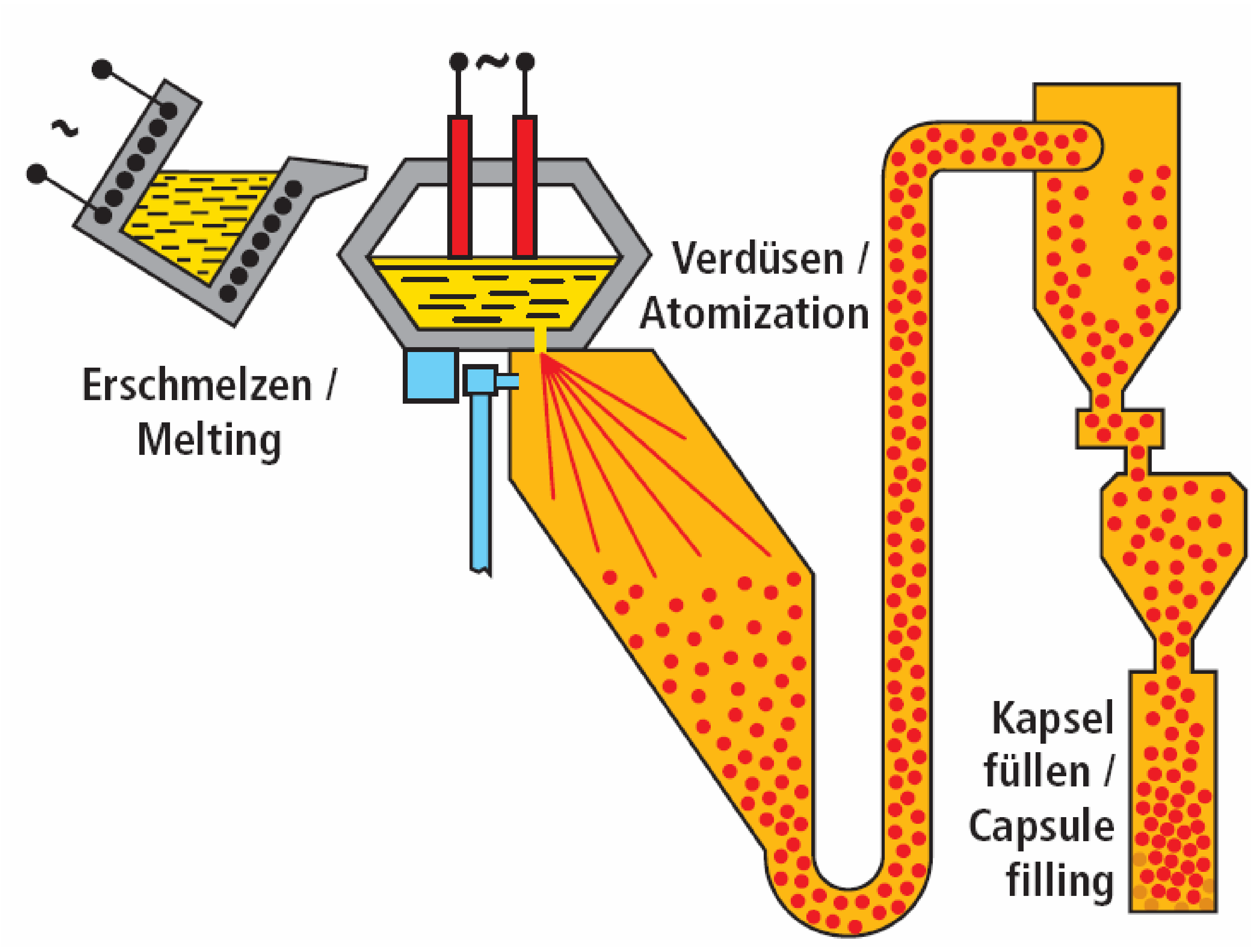
Comparison of toughness and wear resistance



Powder metallurgy

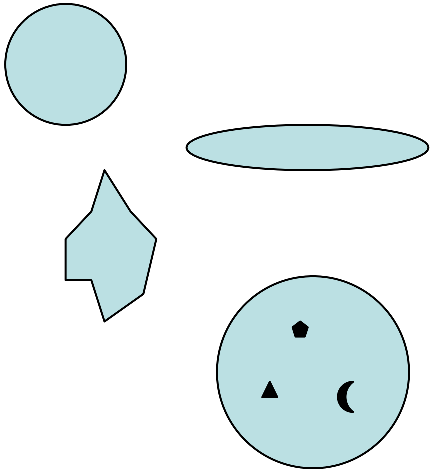
- Production of metal powder
- Mixing and blending
- Compacting
- Sintering
- Forming
- Final treatment
- Tool production

Powder processing



Shape and size of powders

- Shape and size of powders depend on the method of production
- Particle size range: 0,001…1 mm
- Shapes (one-, two, three dimensional):
  - spherical
  - elongated
  - irregular
  - porous

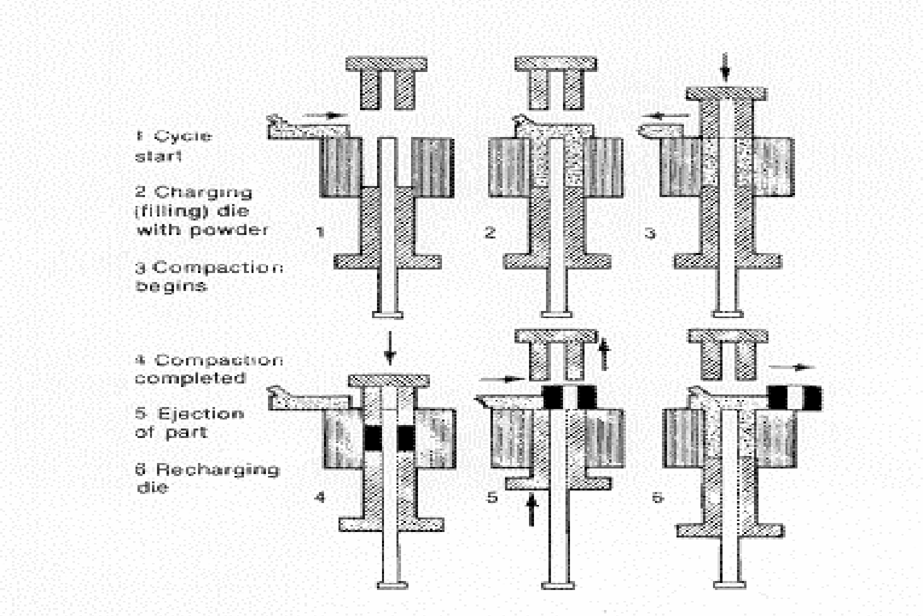


Blending metal powders

- Screening by screens of various mesh sizes
- Mixing by size and by material to uniform distribution of components
- Lubrication
- Objective:
  - Favourable composition
  - Better properties
  - Lower friction at compaction

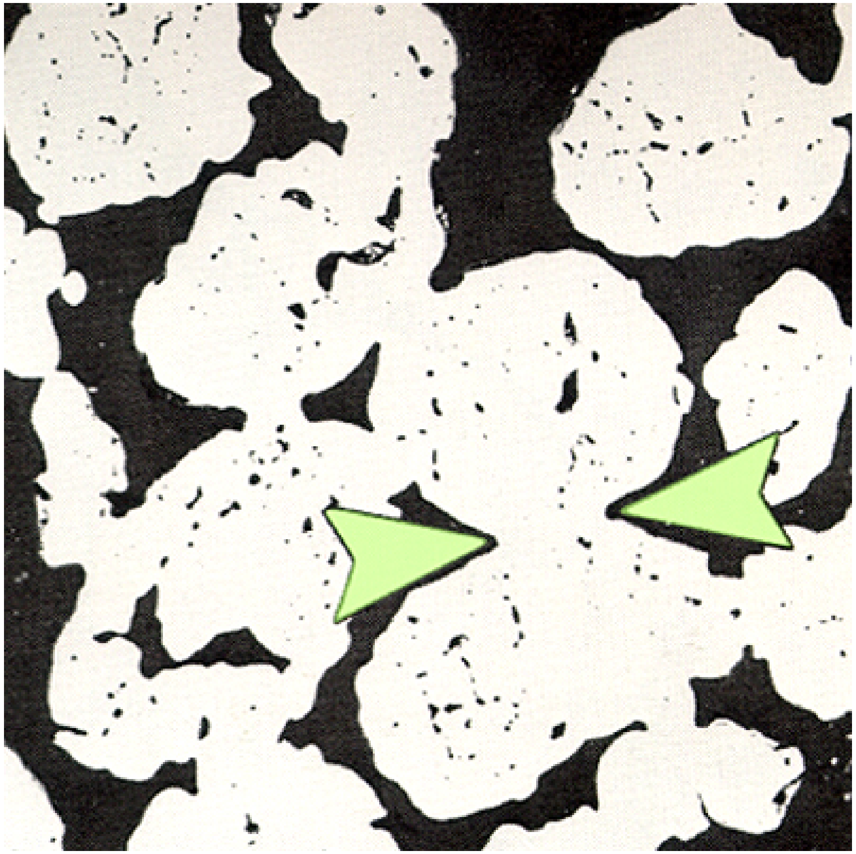
Compaction

- Blended powders are pressed into shapes in dies
- The pressed powder is known as green compact (rigid, low strength)
- Tooling:
  - Single acting punch
  - Floating container
  - Two counteracting punches

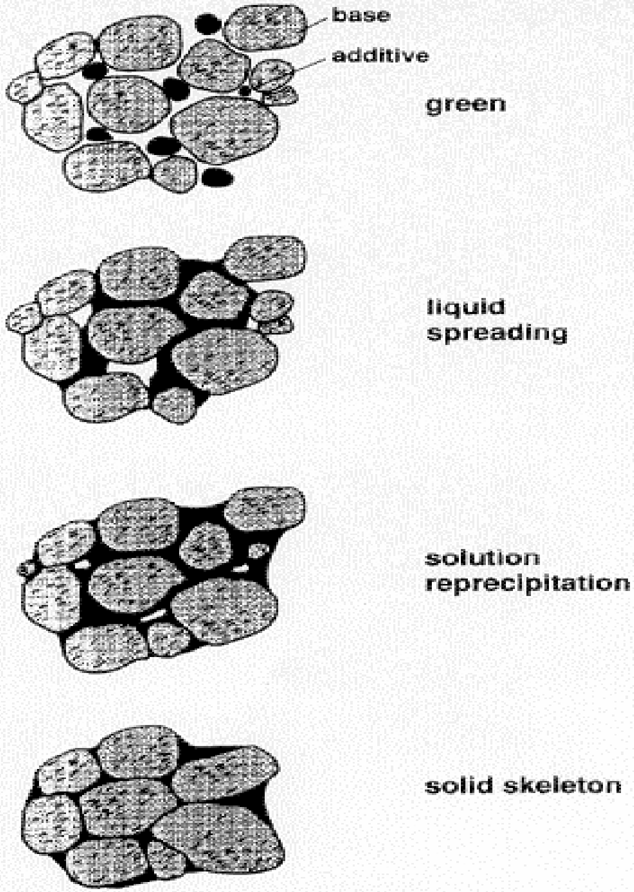


Sintering (process)

- Compressed powder is heated in controlled atmosphere
- Variables: temperature, atmosphere and time
- Result:
  increasing strength and toughness,
  lowering porosity.



Sintering (microstructure)



The conceptual stages to liquid phase sintering

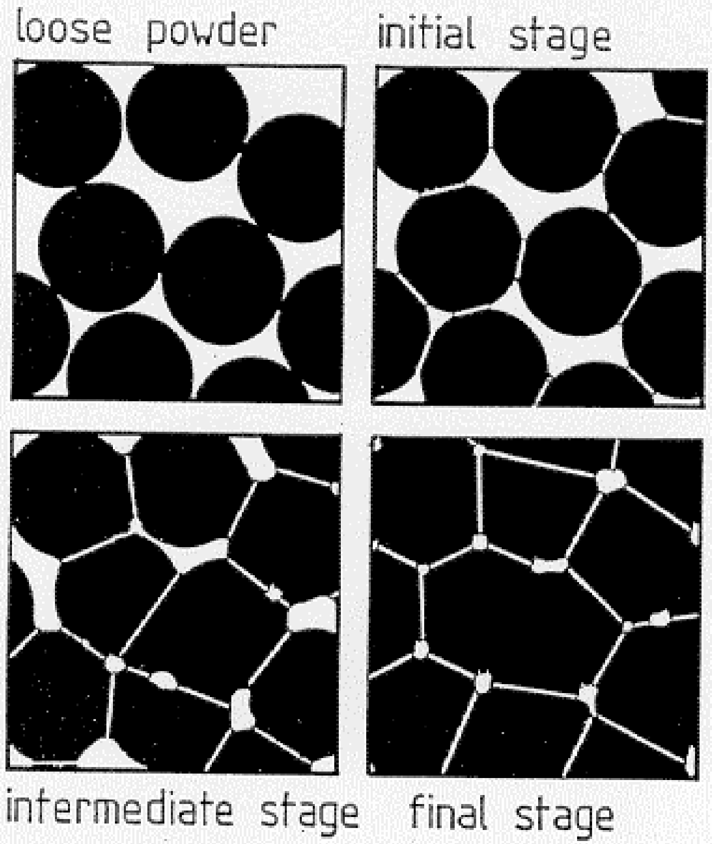
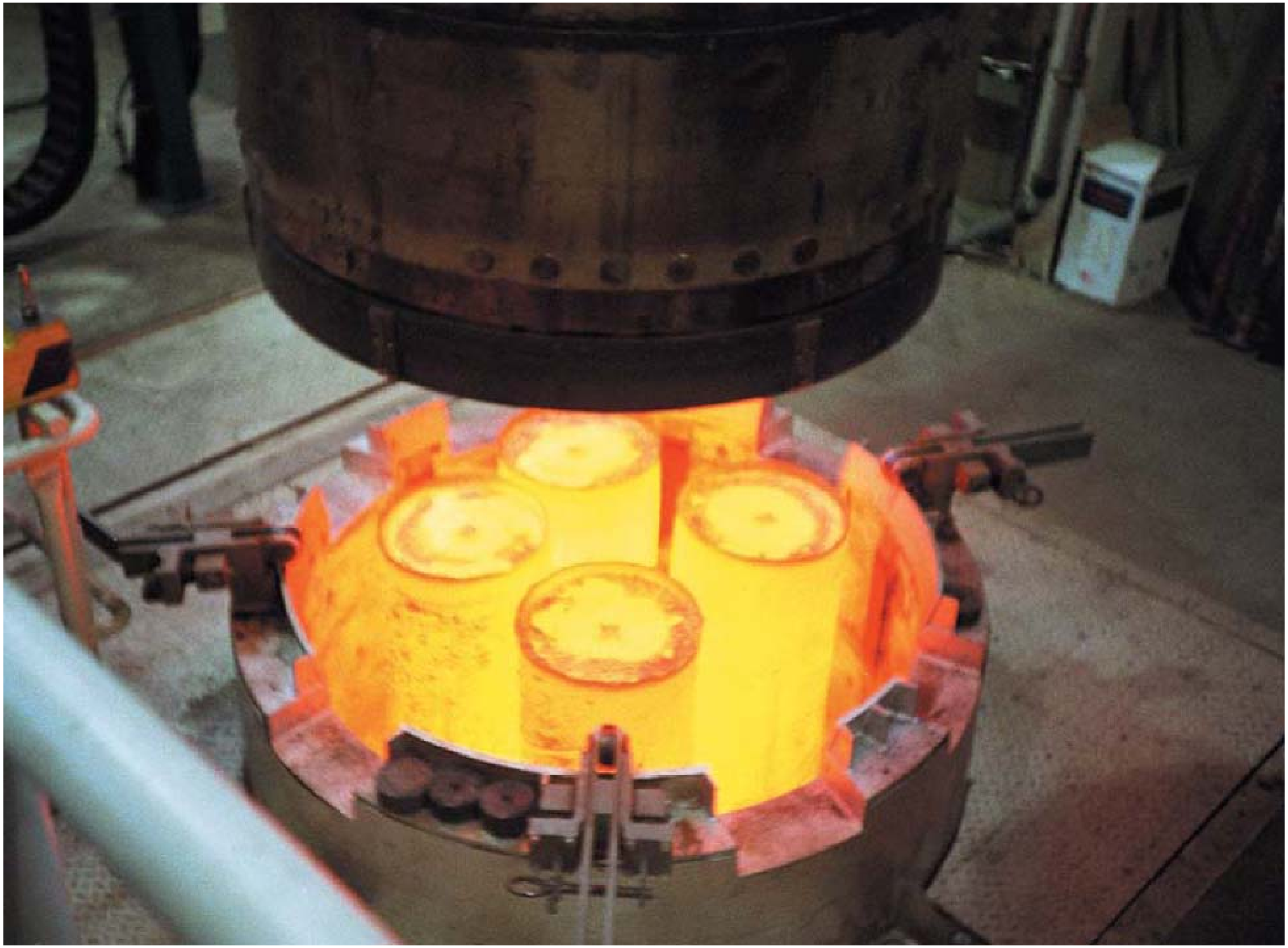


Figure 1: Schematic of loose powder sintering (20).

Sintering (furnace)



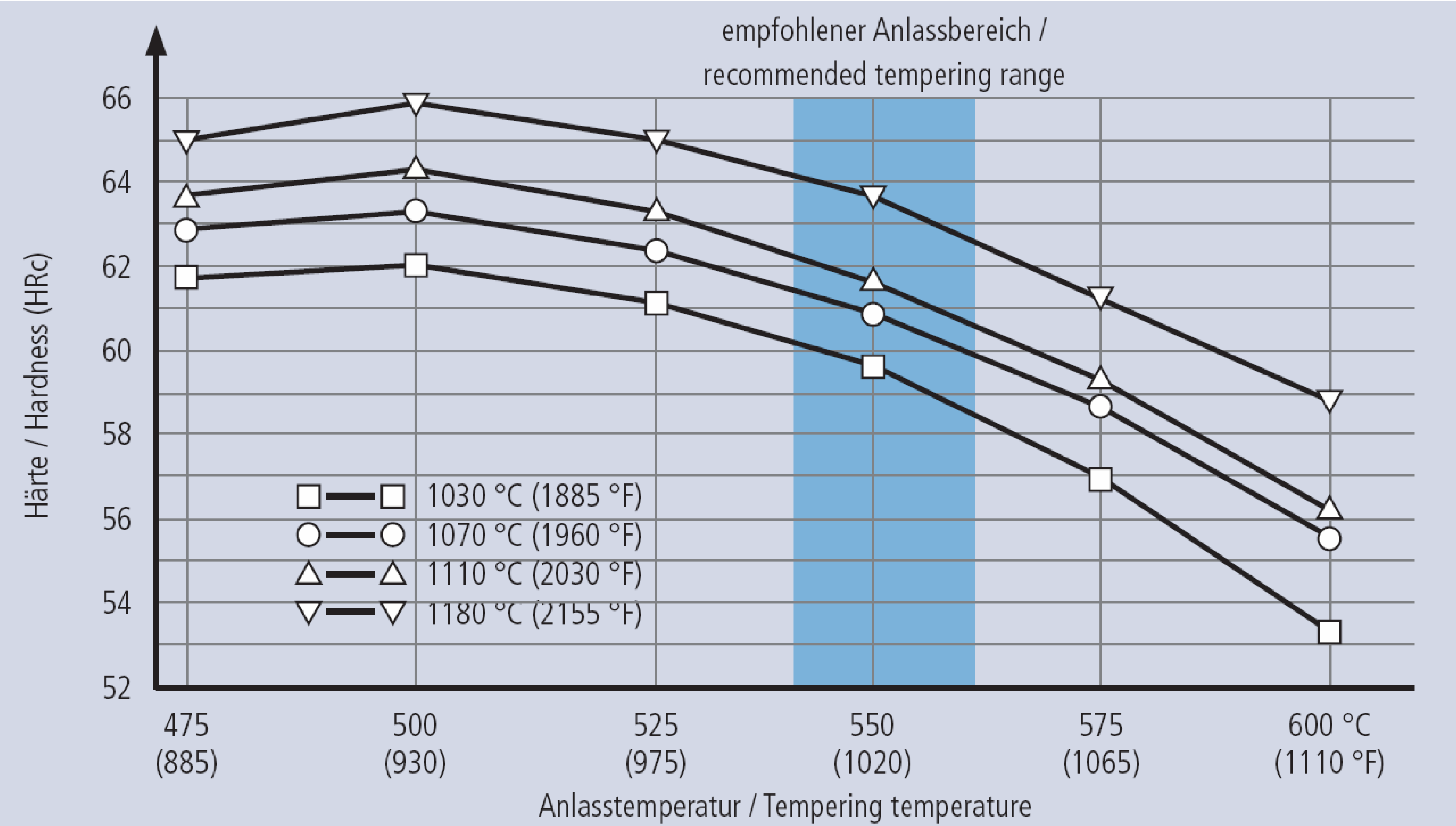
Hardening

- 1030 to 1180 °C (1885 – 2155 °F)/oil, N_2
- Following temperature equalisation:
  20 – 30 minutes for a hardening temperature of 1030 – 1150°C (1885 – 2100 °F)
  10 minutes for a hardening temperature of 1180 °C (2155 °F)
- Where higher toughness is required use a lower hardening temperature
- Where higher wear resistance is required use a higher hardening temperature
- Achievable hardness: up to 66 HRC

Tempering

- Slowly heat to tempering temperature immediately after hardening.
- Time in furnace: 1 hour for every 20 mm (0.79 inch) of workpiece thickness but at least 2 hours.
- Cool in air.
- We recommend that the steel be tempered at least 3 times.

Anlassschaubild / Tempering chart



gehärtet in Vakuum: N_2-Abkühlung 5 bar

hardened in vacuum furnace: N_2 cooling, 5 bar

CCT diagram of K390

ZTU-Schaubild für kontinuierliche Abkühlung / Continuous cooling CCT curves

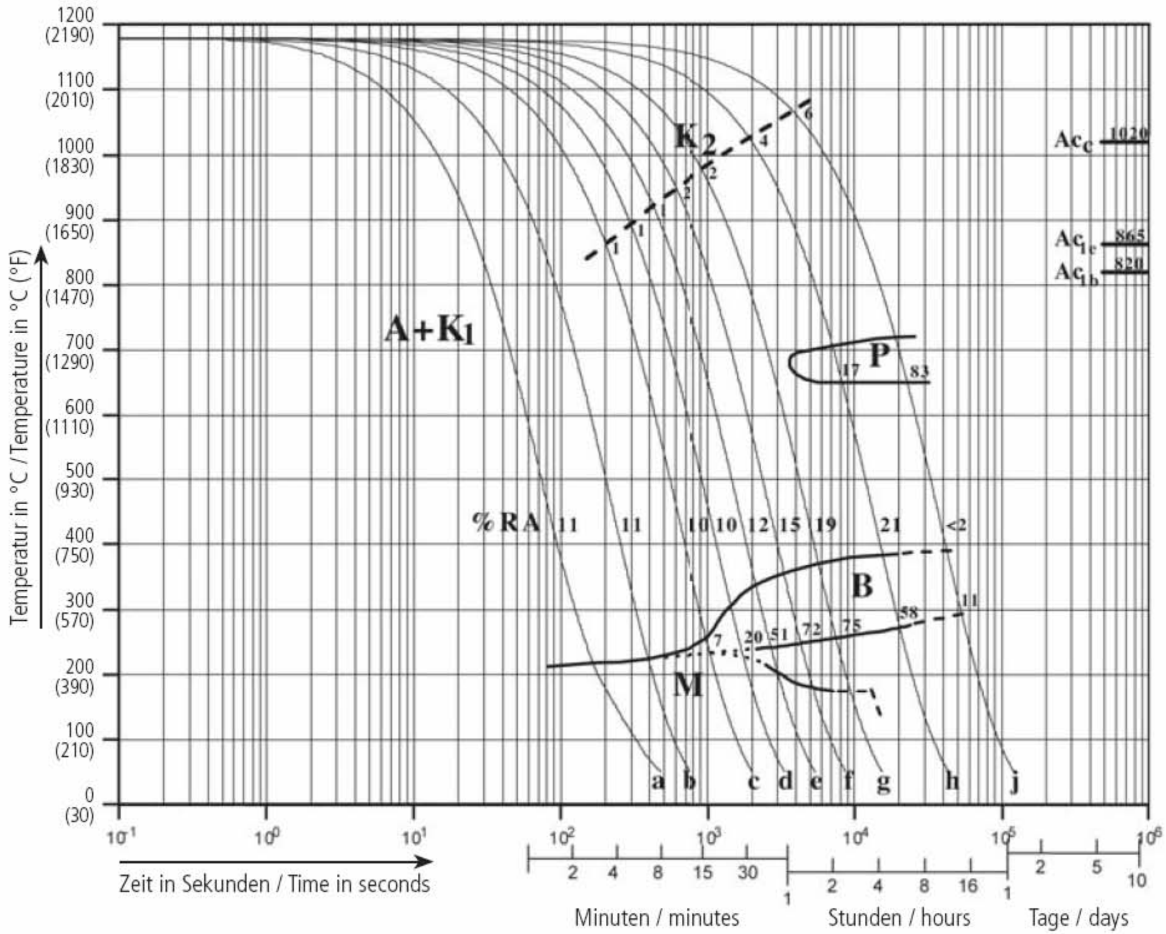
Austenitisierungstemperatur: 1180 °C
Haltedauer: 5 Minuten

0,4 … 180 Abkühlungsparameter, d.h. Abkühlungsdauer von 800 – 500 °C in s x 10-2

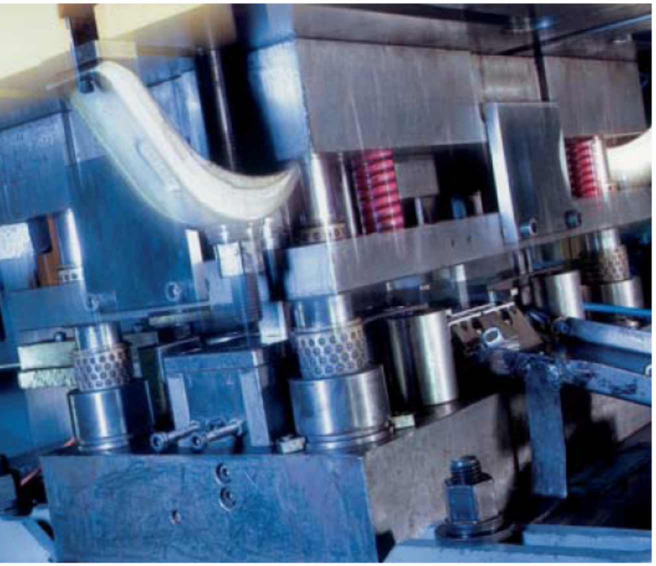
Austenitizing temperature: 1180 °C (2155 °F)
Holding time: 5 minutes

0,4 … 180 cooling parameter, i.e. duration of cooling from 800 – 500° C (1470 – 930 °F) in s x 10-2

Probe / Sample	λ	HV_{10}
a	0,4	931
b	1,1	919
c	3,0	866
d	5,0	870
e	8,0	819
f	13,0	728
g	23,0	635
h	65,0	564
j	180,0	371



Applications (forming tools)



Die besonderen Vorteile dieses PM-Stahles kommen in vielen Anwendungsgebieten zur Geltung:

Stanztechnik

- Schneidwerkzeuge (Matrizen, Stempel) – Normal- und Feinschneiden
- Schneidrollen

Kaltumformtechnik

- Fließpresswerkzeuge (kalt und halbwarm)
- Zieh- und Tiefziehwerkzeuge
- Prägewerkzeuge
- Gewindewalzwerkzeuge
- Kaltwalzen für Mehrrollengerüste
- Kaltpilgerdorne
- Presswerkzeuge für die keramische und pharmazeutische Industrie
- Sinterpresswerkzeuge

The particular advantages of this PM steel make themselves felt in numerous applications:

Blanking and punching industry

- Cutting tools (dies, punches) for normal and precision blanking
- Cutting rolls

Cold forming applications

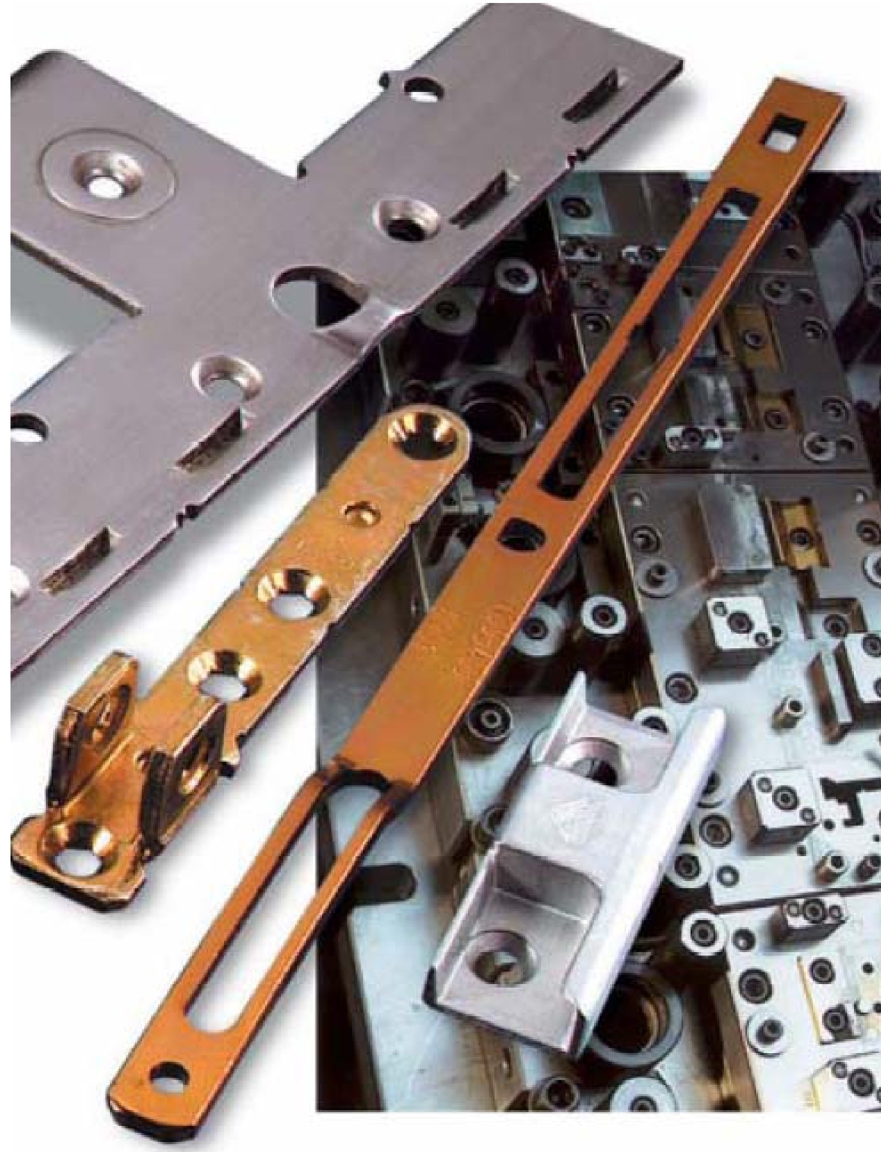
- Extrusion tooling (cold and warm forming)
- Drawing and deep-drawing tools
- Stamping tools
- Thread rolling tools
- Cold rolls for multiple roller stands
- Cold pilger rolling mandrels
- Compression moulding dies for the ceramics and pharmaceutical industries
- Compression moulding dies for the processing of sintered parts.

Easy handling during tool-making due to

- consistent materials properties over the whole cross-section and over the whole length for unproblematic machining
- best grindability – even in deep contours at the centre of the tool
- low and even dimensional change during heat treatment
- highly resilient against overheating or excessive time at temperatur during hardening
- easy electrical discharge machining due to the isotropic distribution of carbides

Advantages for the tool-user

- long tool life
- decreased likelihood of fracture or spalling of cutting edges
- reduction in tooling costs
- reduction of price-per-part and improvement in the quality of the parts being manufactured



Application: cutting tools

W- and Ti-carbide plates for high-speed cutting